STUDYING BIODIVERSITY BY AN INTEGRATIVE APPROACH OF POPULATION GENETICS AND COMMUNITY ECOLOGY:

A WAY TO BETTER PREDICT THE FATE OF OUR MARINE FORESTS IN A CHANGING OCEAN?

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6th European Phycological Congress - August 28th 2015
BIODIVERSITY: A MULTI-LEVEL NOTION

Ecosystem diversity

Species diversity

Genetic diversity
BIODIVERSITY: A MULTI-LEVEL NOTION

Ecosystem diversity

Species diversity

Genetic diversity

- Temperate forest
- Lake
- Desert
- Tropical forest
- Ocean
BIODIVERSITY: A MULTI-LEVEL NOTION

- Ecosystem diversity
- Species diversity
- Genetic diversity

- Temperate forest
- Lake
- Desert
- Tropical forest
- Ocean
Biodiversity: A Multi-Level Notion

- Ecosystem diversity
- Species diversity
- Genetic diversity

Examples:
- Temperate forest
- Lake
- Desert
- Tropical forest
- Ocean
BIODIVERSITY: A MULTI-LEVEL NOTION

- Ecosystem diversity
- Species diversity
- Genetic diversity

Studied recently:
- Temperate forest
- Lake
- Desert
- Tropical forest
- Ocean

Studied independently:
- Snails
1) Identifying processes impacting biodiversity at intra and inter-specific levels

- Genetic diversity
- Species diversity

anthropogenic pressures → genetic diversity → species diversity → conservation measures
INSIGHTS FROM STUDYING BIODIVERSITY BY AN INTEGRATIVE APPROACH

1) Identifying processes impacting biodiversity at intra and inter-specific levels

- Genetic diversity
- Species diversity

anthropogenic pressures → Conservation measures

2) If there is a relation between levels of diversity: use one level of diversity as a surrogate for the other

Genetic diversity → Species diversity

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STUDIED ECOSYSTEM: KELP FORESTS OF BRITTANY

Large brown algae forming underwater marine forests in cold to temperate rocky shores

Ecosystem engineers providing habitat, food and protection to other organisms
STUDIED ECOSYSTEM: KELP FORESTS OF BRITTANY

Large brown algae forming underwater marine forests in cold to temperate rocky shores

Ecosystem engineers providing habitat, food and protection to other organisms

7 kelp species in Brittany, focus on 2 sister species:

**Laminaria hyperborea**
subtidal
Norway to Portugal

**Laminaria digitata**
low intertidal/high subtidal
Norway to Southern Brittany

Photo Yann Fontana

Photo Marine Robuchon
Kelps forests of Brittany are under pressure

1) Climate change
Cold-water species
Temperature impacts survival, growth & reproduction
Mean temperature has increased by 0.7 ° during the last 20 years in Brittany (Gallon, Robuchon et al. 2014, JOB)
Exacerbated pressure for Laminaria digitata
**STUDIED ECOSYSTEM: KELP FORESTS OF BRITTANY**

Kelps forests of Brittany are under pressure

1) Climate change

Cold-water species
Temperature impacts survival, growth & reproduction
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Exacerbated pressure for *Laminaria digitata*

2) Harvesting

*L. hyperborea*
Norwegian comb
Since 2006

*L. digitata*
Scoubidou
Since 1960’s
Origin of SGDC studies

Janis Antonovics

The forces maintaining species and genetic diversity are similar (1976, *Syst Bot*)
STUDIED RELATION: SPECIES GENETIC DIVERSITY CORRELATION (SGDC)

Origin of SGDC studies

The forces maintaining species and genetic diversity are similar (1976, *Syst Bot*)

<table>
<thead>
<tr>
<th></th>
<th>Genetic diversity</th>
<th>Species diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Within &amp; among populations</em></td>
<td><em>Within &amp; among communities</em></td>
</tr>
<tr>
<td><strong>Drift</strong></td>
<td>Random fluctuations in the abundance of genes</td>
<td>Random fluctuations in the abundance of species</td>
</tr>
<tr>
<td><strong>Migration</strong></td>
<td>Movement of genes among localities</td>
<td>Movement of species among localities</td>
</tr>
<tr>
<td><strong>Selection</strong></td>
<td>Favours a genotype over others</td>
<td>Favours a species over others</td>
</tr>
</tbody>
</table>
STUDIED RELATION: SPECIES GENETIC DIVERSITY CORRELATION (SGDC)

Test of SGDC across islands in 14 datasets

Genetic diversity of *Urocyon littoralis*
Channel Islands, CA
Data for 6 islands

Species diversity of terrestrial mammals

© B. Moose Peterson, www.mnh.si.edu

Test of SGDC across islands in 14 datasets

Positive SGDC in 13 out of 14 datasets explained by island size
**STUDIED RELATION: SPECIES GENETIC DIVERSITY CORRELATION (SGDC)**

Summary of processes explaining SGDC patterns

Case 1: parallel effects

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Genetic diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>correlation +</td>
</tr>
<tr>
<td>Connectivity</td>
<td>correlation +</td>
</tr>
<tr>
<td>Heterogeneity</td>
<td>correlation ?</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
</tr>
</tbody>
</table>

Parallel effects:
- drift
- selection
- migration

Species diversity
Summary of processes explaining SGDC patterns

Case 1: parallel effects

Habitat
- Size
- Connectivity
- Heterogeneity
- Environment

Parallel effects
- drift
- selection
- migration

Genetic diversity
- correlation +
- correlation +
- correlation ?

Species diversity

Ex: SGDC + in Vellend 2003, Am Nat

Islands of different sizes

Populations/communities size

Drift
Summary of processes explaining SGDC patterns

Case 2: causal effects

- Habitat
  - Size
  - Connectivity
  - Heterogeneity
  - Environment

- Genetic diversity
  - Causal effects: competition, facilitation
  - Parallel effects: correlation - , correlation +

- Species diversity
STUDIED RELATION: SPECIES GENETIC DIVERSITY CORRELATION (SGDC)

Summary of processes explaining SGDC patterns
Case 2: causal effects

Ex: SGDC - in Karlin et al. 1984, Copeia

Habitats of different species richness

Interspecific competition

Genetic diversity

Causal effects

Species diversity

Parallel effects

Genetic diversity

correlation -
correlation +

competition

facilitation

Habitat
Size
Connectivity
Heterogeneity
Environment
LOOKING FOR SGDC IN KELP FORESTS OF BRITTANY

20 sites sampled in 4 regions along the Brittany coastline during the winter 2011
LOOKING FOR SGDC IN KELP FORESTS OF BRITTANY

20 sites sampled in 4 regions along the Brittany coastline during the winter 2011

1) Genetic diversity of *L. hyperborea* and *L. digitata*

Genotyping (microsatellites) of 30 to 50 specimens/site/species (Robuchon et al. 2014, *Mol Ecol*)
20 sites sampled in 4 regions along the Brittany coastline during the winter 2011

1) Genetic diversity of *L. hyperborea* and *L. digitata*
Genotyping (microsatellites) of 30 to 50 specimens/site/species (Robuchon et al. 2014, *Mol Ecol*)

2) Species diversity of algal communities living beneath *L. hyperborea* and *L. digitata*
Integrative identification of specimens sampled in 3 0.1 m$^2$ quadrats/site/species (Robuchon et al. 2015, *Genetica*)
Looking for SGDC in kelp forests of Brittany

Calculation of equivalent diversity metrics at both diversity levels by site

<table>
<thead>
<tr>
<th>Genetic diversity</th>
<th>Species diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allelic richness</td>
<td>Species richness</td>
</tr>
<tr>
<td>AR</td>
<td>SR</td>
</tr>
<tr>
<td>Gene diversity</td>
<td>Simpson diversity</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>2</td>
</tr>
<tr>
<td>He = $1-\sum p_i^2$</td>
<td>$1-\lambda = 1-\sum p_i^2$</td>
</tr>
<tr>
<td>Genetic structure</td>
<td>Community structure</td>
</tr>
<tr>
<td>$\beta$</td>
<td>4</td>
</tr>
<tr>
<td>$F_{ST} = \sigma_a^2/(\sigma_a^2 + \sigma_b^2 + \sigma_w^2)$</td>
<td>$F_{STC} = \sigma_a^2/(\sigma_a^2 + \sigma_b^2)$</td>
</tr>
</tbody>
</table>

Where $\sigma_a$, $\sigma_b$, and $\sigma_w$ are the components of variance of allele (resp. species) frequencies among populations (resp. communities), among individuals within populations (resp. communities), within individuals (resp. $= 0$)

Correlation tests between species and genetic diversity carried out

*L. hyperborea* vs. *L. digitata*

Genetic diversity of the kelp species

Species diversity of the algal community
Correlation tests between species and genetic diversity carried out

L. hyperborea

Genetic diversity of the kelp species

versus

Species diversity of the algal community

L. digitata

Richness-based

Frequency-based

Variance-based

(AR versus SR)

(He versus 1-\(\Lambda\))

\(F_{ST} \) versus \(F_{STC}\)
Correlation tests between species and genetic diversity carried out between:

- **L. hyperborea**
- **L. digitata**

Species diversity of the algal community versus genetic diversity of the kelp species.

**Richness-based**
- (AR versus SR)

**Frequency-based**
- (He versus 1-\(\Lambda\))

**Variance-based**
- (F\(_{ST}\) versus F\(_{STC}\))

Areas under consideration:
- St Malo Bay
- Morlaix Bay
- Iroise Sea
- Southern Brittany

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SGDC IN KELP FORESTS OF BRITTANY: VARIATION AMONG SPECIES

Pearson correlation tests

\[ p < 0.01, r = 0.57 \]

Richness-based metrics

Brittany

\[ \text{L. hyperborea} \]

\[ \text{L. digitata} \]

all sites: \( p > 0.05 \)
**SGDC in Kelp Forests of Brittany: Variation Among Species**

Pearson correlation tests

- **L. hyperborea**
  - Richness-based metrics (AR versus SR)
  - [Graph showing correlation with species richness]
  - $p < 0.01$, $r = 0.57$

- **Brittany**
  - [Graph showing correlation with species richness]
  - Without Southern Brittany: $p < 0.01$, $r = 0.72$

- **L. digitata**

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SGDC IN KELP FORESTS OF BRITTANY: VARIATION AMONG SPECIES

Pearson correlation tests

**L. hyperborea**

Richness-based metrics

(AR versus SR)

**Brittany**

**L. digitata**

Range limit effect?

\[ p < 0.01, r = 0.57 \]

all sites: \( p > 0.05 \)

without Southern Brittany: \( p < 0.01, r = 0.72 \)
SGDC in kelp forests of Brittany: variation among metrics

Pearson correlation tests

- Frequency-based metrics (He versus 1-λ)
  - all sites: p > 0.05
  - without Southern Brittany: p < 0.01, r = 0.72

- Richness-based metrics (AR versus SR)
  - all sites: p < 0.05, r = 0.49
  - without Southern Brittany: p < 0.01, r = 0.46

Brittany

L. digitata

L. digitata

all sites: p < 0.05, r = 0.49
without Southern Brittany: p < 0.01, r = 0.46

all sites: p > 0.05
without Southern Brittany: p < 0.01, r = 0.72
SGDC IN KELP FORESTS OF BRITTANY: VARIATION AMONG METRICS

Pearson correlation tests

**Frequency-based metrics**
(He versus 1-ʎ)

- Positive SGDC
  - He = 0.62
  - - 18 %
    - Low impact

- Brittany

**Richness-based metrics**
(AR versus SR)

- No SGDC
  - AR = 2
  - He = 0.50
  - - 50 %
    - Strong impact

L. digitata

Bottleneck effect?
Pearson correlation tests

**Richness-based metrics**

(AR versus SR)

*L. hyperborea*

all sites: *p < 0.01, r = 0.57*
Pearson correlation tests

**Richness-based metrics** (AR versus SR)

*L. hyperborea*

---

all sites: $p < 0.01$, $r = 0.57$

St Malo Bay: $p < 0.05$, $r = 0.88$
**SGDC in kelp forests of Brittany: variation across scales**

Pearson correlation tests

**Richness-based metrics** (AR versus SR)

- **L. hyperborea**

- **Scale-dependant processes?**

- **all sites:** $p < 0.01$, $r = 0.57$
- **St Malo Bay:** $p < 0.05$, $r = 0.88$
- **Morlaix Bay:** $p > 0.05$
- **Iroise Sea:** $p > 0.05$
- **Southern Brittany:** $p > 0.05$
SGDC in kelp forests of Brittany: summary

SGDC at the scale of Brittany:

<table>
<thead>
<tr>
<th></th>
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<th>L. digitata</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Richness-based</strong>&lt;br&gt;(AR vs SR)</td>
<td>+</td>
<td>All sites: 0&lt;br&gt;Without Southern Brittany: +</td>
</tr>
<tr>
<td><strong>Frequency-based</strong>&lt;br&gt;(He vs 1-(\Lambda))</td>
<td>+</td>
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</tr>
<tr>
<td><strong>Variance-based</strong>&lt;br&gt;(F(_ST) vs F(_STC))</td>
<td>+</td>
<td>All sites: +&lt;br&gt;Without Southern Brittany: +</td>
</tr>
</tbody>
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### SGDC within regions:

<table>
<thead>
<tr>
<th></th>
<th>St Malo Bay</th>
<th>Morlaix Bay</th>
<th>Iroise Sea</th>
<th>South. Brittany</th>
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<tr>
<td><strong>Richness-based</strong> (AR vs SR)</td>
<td>+</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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A MAJORITY OF POSITIVE SGDC: PREVALENCE OF NEUTRAL PROCESSES?

Brittany: 8 out of 9 positive SGDC

Genetic diversity characterised by neutral markers

Parallel action of neutral processes on both species and genetic diversity

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Parallel effects

Habitat
- Size
- Connectivity
- Heterogeneity
- Environment

Genetic diversity

Species diversity

Causal effects
- competition
- facilitation

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Drift
Selection
Migration

---

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Variation of SGDC patterns: what do they reveal?

<table>
<thead>
<tr>
<th>All sites: no SGDC</th>
<th>All sites: SGDC +</th>
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<tbody>
<tr>
<td>for richness-based metrics</td>
<td>for frequency-based metrics</td>
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</table>

Without Southern Brittany: SGDC + for richness-based metrics

In Southern Brittany, environmental filters seem to affect *L. digitata* negatively. For instance, reproduction is affected by high temperatures (Oppliger et al. 2014, *PLoS ONE*)

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**Variation of SGDC patterns**

- Habitat
  - Size
  - Connectivity
  - Heterogeneity
  - Environment

- Parallel effects
  - drift
  - selection
  - migration

- Genetic diversity

- Causal effects
  - competition
  - facilitation

- Species diversity

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VARIATION OF SGDC PATTERNS: WHAT DO THEY REVEAL?

Brittany: 8 out of 9 positive SGDC

Intra-region: 1 out of 21 positive SGDC

Processes vary with scale
VARIATION OF SGDC PATTERNS: WHAT DO THEY REVEAL?

Brittany: 8 out of 9 positive SGDC
Intra-region: 1 out of 21 positive SGDC

Processes vary with scale
Neutral processes seem to dominate at large scale

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<tr>
<td>drift</td>
<td>migration</td>
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<tr>
<td>selection</td>
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Variation of SGDC patterns: what do they reveal?

Brittany: 8 out of 9 positive SGDC
Intra-region: 1 out of 21 positive SGDC

Processes vary with scale
Neutral processes seem to dominate at large scale
Deterministic processes seem to play an important role at small scale

Habitat
Size
Connectivity
Heterogeneity
Environment

Parallel effects
- drift
- selection
- migration

Genetic diversity
Species diversity

Causal effects
- competition
- facilitation
Drift and migration act in parallel on both species and genetic diversity

>> Conservation measures aiming at preserving an important diversity at both intra and inter specific levels should
Implications for predicting the fate of our marine forests

Drift and migration act in parallel on both species and genetic diversity

>> Conservation measures aiming at preserving an important diversity at both intra and inter specific levels should

1) Reduce drift
   e.g. by protecting large areas of kelp forests
Drift and migration act in parallel on both species and genetic diversity

>> Conservation measures aiming at preserving an important diversity at both intra and inter specific levels should

1) Reduce drift
e.g. by protecting large areas of kelp forests

2) Promote migration
e.g. by reducing the impact of kelp harvesting on connectivity

Photo Wilfried Thomas
L. digitata populations at their southern range limit are vulnerable to climate change

>> Conservation measures aiming at preserving those populations should be strict to maintain them as well as the rich community living beneath their canopy
*L. digitata* populations at their southern range limit are vulnerable to climate change

>> Conservation measures aiming at preserving those populations should be strict to maintain them as well as the rich community living beneath their canopy

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*L. digitata* in Southern Brittany

Low genetic diversity
Alteration of reproduction
**Implications for predicting the fate of our marine forests**

*L. digitata* populations at their southern range limit are vulnerable to climate change.

>> Conservation measures aiming at preserving those populations should be strict to maintain them as well as the rich community living beneath their canopy.

*L. digitata* in Southern Brittany
- Low genetic diversity
- Alteration of reproduction


Sacchorhiza polyschides in Southern Portugal
- Low density
- Low connectivity

The relative importance of neutral and deterministic processes seem to vary across scales.

>> A better understanding of how the different processes vary across scales would help to improve the robustness of conservation measures.
The relative importance of neutral and deterministic processes seem to vary across scales.

>> A better understanding of how the different processes vary across scales would help to improve the robustness of conservation measures.

Disentangling the processes of community assembly across scales with ecophylogenetics

The relative importance of neutral and deterministic processes seem to vary across scales.

>> A better understanding of how the different processes vary across scales would help to improve the robustness of conservation measures.


**Phylogenies**

Le Gall et al. 2010, *J Phycol*

Verbruggen et al. 2010, *BMC Evol Biol*

Silberfeld et al. 2014, *Cryptogamie Algol*

**Species traits**

Construction of a species trait database for European seaweed species (EMODnet project).

- Distribution
- Habitat
- Life history
- Morpho-functionality